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PROGRESS IN MAIZE HYBRIDS BREEDING BASED ON
OFFICIAL REGISTRATION TRIALS IN POLAND
IN LAST 20-YEAR PERIOD

ABSTRACT

The progress in breeding of grain and silage hybrids was analysed based on results of the official testing of maize hybrids during 20 years from 1981 to 2000. A number of maize hybrids tested significantly increased in 1990's. Competition between seed companies resulted in big progress of both usage types (grain and silage). This progress was expressed by over 45% increase of the mean grain yield in all hybrid groups. At the same time farmers obtained much lower yields, which indicates a small ability to take advantage of hybrids potential productivity. Positive progress was obtained in limitation of lodging (almost 8%). Plant health was improved in many new hybrids but average data did not show significant progress in this aspect.

Number of hybrids tested for silage was much lower than for grain. During 20 years nearly 38% increase of total dry matter yield (average for hybrids) was evidenced. Significant progress was observed in ear yields (52%), content of ears in total dry matter, which indicates a progress also in silage quality. Fodder units yield increased by 37.5% (average for all hybrids) during this period.

Key words: grain, maize hybrids, progress in breeding, silage

INTRODUCTION

Seed industry is one of the most profitable and its value in 1994 worldwide amounted 2.900 mln USD after oil, electronics, insurance and hotel businesses. The value of maize seeds among other crops was the highest and amounted 400 mln USD in 1994. followed by potato seeds, sugar beet and wheat (Runowski 1997). Nowadays the value of worldwide seed industry is estimated up to 4.5 – 5 bln USD.

Maize breeding and seed production is specific because only hybrid varieties are grown and registered in Poland. This type of varieties is yielding higher, but each year the farmers have to buy new seeds. The cost of maize seeds is higher and refers to value turnover in this business.

The original concept of maize hybrids proposed in 1908 by G.H. Shull was based on single cross hybrids (SC). Technical and economical difficulties caused that practical value of hybrid breeding was achieved only when Jones proposed in 1917 the formula of double cross hybrid (DC), yielding higher at lower production cost. The compromise between lower production costs and higher hybrid effect was found in three-way cross hybrids (TC). History of hybrid maize breeding in Poland is almost 50 years old (the first hybrid Wiel-Wi was registered in 1957 (Adamczyk 2002)), but compared with such countries like USA, France or Germany, it seems to be a rather short period. Bojanowski (1994) and Królikowski *et al.* (1994) during its 40th anniversary mentioned the achievements and history of Polish maize breeding.

Area under maize in Poland was the highest in late 70's and amounted up to app. 700.000 ha. At that time maize was mainly grown for silage in large state farms. Political and economical changes caused decrease of this area. The lowest area in analysed 20 years period was recorded in 1995 and amounted only 181.000 ha, then it gradually increased, but at this time maize was mainly grown for grain. In 2000 the total area under maize was three times higher than in 1995 and covered 315.000 ha.

MATERIAL AND METHODS

This overview was based on annual summary of registration trial results published by COBORU (Research Centre for Testing Varieties) (Kukurydza pastewna – syntezy wyników doświadczeń odmianowych COBORU 1981-2000).

The analysis was done by calculation of mean values for maize hybrids in particular maturity groups and usage types (grain and silage). For each character, correlation coefficient and regression formulas were calculated followed by finding the best trend line. To compare the progress in practical farming with COBORU trial results, based on official statistic data from GUS (National Statistic Office) (Rocznik Statystyczny GUS 1982-2001), regression curve for grain yield was found and compared with those curves found for registration trials in particular maturity groups. Data concerning the number of registered hybrids and particular registered hybrid types were collected from official variety list published annually by COBORU (Lista odmian roślin rolniczych 1981-2001).

The graphs were done based on regression formulas introduced for years 1982 – 2001. Numbers 1 to 20 describe following years.

Maize is grown in Poland for grain or silage, and below analysis of breeding progress was done in reference to both ways of crop usage.

PROGRESS IN GRAIN MAIZE BREEDING

Maize grown for grain is one of the most profitable crops in Polish agriculture, therefore breeding companies are interested in introduction of their grain hybrids to Polish market.

Table 1

Total number of maize hybrids in official testing for grain

Year	Polish hybrids			Foreign hybrids			Total hybrids		
	Early	Medium early	Medium late	Early	Medium early	Medium late	Early	Medium early	Medium late
1981	2	3	3	7	10	4	9	13	7
1982	2	4	1	8	6	4	10	10	5
1983	6	5	0	7	7	4	13	12	4
1984	4	5	1	9	8	4	13	13	5
1985	5	2	1	12	8	4	17	10	5
1986	6	4	3	10	9	3	16	13	6
1987	4	4	1	6	8	4	10	12	5
1988	5	2	0	7	10	5	12	12	5
1989	6	5	0	6	7	9	12	12	9
1990	6	6	2	6	9	7	12	15	9
1991	8	7	1	4	12	7	12	19	8
1992	6	6	2	5	15	9	11	21	11
1993	9	4	4	7	13	13	16	17	17
1994	10	11	3	10	14	12	20	25	15
1995	10	15	3	9	15	11	19	30	14
1996	9	13	8	7	23	12	16	36	20
1997	5	13	9	8	25	10	13	38	19
1998	10	19	3	3	26	15	13	45	18
1999	7	4	0	4	13	7	11	17	7
2000	4	12	0	7	18	15	11	30	15

In analysed 20 years period, the number of grain hybrids tested by COBORU was the highest in the early and medium early group (Table 1). In 1980's the majority of hybrids were from early group, while in 1990's the medium hybrids prevailed. This change followed the production needs, since the hybrids from the medium group were grown most frequently. Domestic early and medium early hybrids, which are mostly grown in Poland, have particularly strong position (Adamczyk 2002). Relatively large number of hybrids was tested each year, which guaranteed rapid progress of yield and economical value. Michalski (2002) also underlines, that part of hybrids are withdrawn after 3-4 years, which means that the lifetime of hybrids got shorten. Particularly large number of grain hybrids was tested in 1994 – 1998 because of increasing interest of farmers in growing maize for grain.

Progress in maize hybrid breeding can be expressed not only by large number of hybrids applied for testing and registered, but mainly by

their increased economical value. The testing system carried out by COBORU is very strict. Along the testing period, the hybrids worse than standard in only one of important characters are eliminated. In testing of grain hybrids, yield is one of the important characters (Fig. 1). In analysed 20 years period medium late hybrids yielded the best and early ones the least, which confirms a negative correlation between maturity and yielding. Regression curves show faster progress in yield in 1990's than in 1980's, irrespectively of the maturity group. The increase of yield amounted from 44% in early group to 46% in medium early group. This progress observed in registration trials at COBORU was not fully reflected in practical production, where trend line was more flat. The yield level achieved by farmers was significantly lower, because of crop management errors and economical difficulties in 1990's. For these reasons farmers were not able to use the full potential of new, better hybrids. There is big gap observed between trend lines of yields from COBORU trials and production yields recorded by national statistical office.

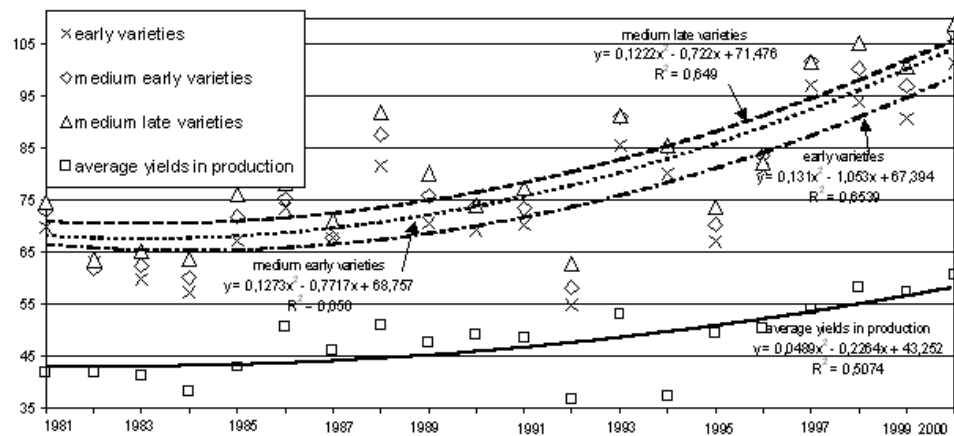


Fig. 1 Grain yield [dt/ha]

Grain moisture at harvest is a very important parameter in hybrid evaluation for grain purposes, as drying costs amount up to 30% of the total production costs. In each of the analysed maturity group it was impossible to find any rule of this character. Data are presented in Table 2. This does not mean a lack of progress, but reflects large influence of weather conditions. There are hybrids both in testing trials and in those already registered, which dry down fast and can be harvested at lower moisture, but this progress cannot be referred to the whole maturity group.

Similarly to grain moisture at harvest, number of vegetation days is the character depended mainly on weather conditions (Table 3). It is

Grain moisture [%] at harvest

Table 2

Year	Maturity group		
	Late	Medium early	Medium late
1981	33.3	34.3	35.7
1982	26.6	27.8	29.2
1983	28.3	29.8	31.4
1984	35.8	37.5	38.6
1985	35.0	36.4	36.9
1986	32.7	34.6	36.5
1987	38.6	40.1	41.5
1988	29.7	32.1	32.4
1989	27.8	29.9	31.5
1990	30.2	31.9	33.2
1991	30.4	32.5	34.5
1992	25.5	27.2	28.1
1993	31.5	33.1	35.1
1994	29.2	31.6	33.1
1995	29.8	31.5	32.2
1996	34.6	35.4	36.8
1997	31.1	31.6	32.9
1998	30.7	31.2	31.6
1999	25.5	25.1	26.4
2000	29.4	29.2	30.6

Number of days from emergence to full grain maturity

Table 3

Year	Maturity group		
	Early	Medium	Late
1981	123	128	132
1982	114	116	119
1983	114	118	123
1984	139	143	146
1985	135	139	140
1986	131	136	137
1987	136	137	141
1988	135	138	144
1989	125	128	132
1990	138	138	145

difficult to show a progress in this character within maturity groups, but there are examples of very early hybrids.

Table 3

Year	Continued		
	Maturity group		
	Early	Medium	Late
1991	135	139	143
1992	114	117	120
1993	138	143	148
1994	128	133	138
1995	119	122	126
1996	137	143	147
1997	129	136	141
1998	131	134	145
1999	114	120	127
2000	133	136	142

Table 4

Progress in maize grain hybrids expressed by yield increase and selected characters

Character	Mean annual increase	Increase in years 1981-2000
Grain yield	1.65 dt/ha	45.2 %
Grain moisture at harvest	-0.24 %	-13.6 %
Percent of standing plants	0.4 %	7.98 %
European corn borer infestation	-0.08 %	-13.3 %
Smut infestation	0.008 %	0.15 %
Fusariosis infestation	0.44 %	8.7 %

Summary of the progress in grain maize hybrids tested in 1981 – 2000

The progress in grain maize breeding is high as the mean annual yield amounted 1.65 dt/ha, which means a 45% increase within 20 years (Table 4). As shown by Bilski and Siódmiak (1994) annual yield increase in 30 years period (1962 – 1992) was 1.25 dt/ha for domestic hybrids (coefficient of linear regression). Taking into consideration the fact, that at that time most of varieties were hybrids, the real increase was lower, i.e. 0.79 dt/ha for domestic hybrids and 0.83 for foreign ones. This comparison is not very precise, because obtained curves were parabolic. There are no coefficients for these equations. Parabola as trend line of yield increase in 20 years period is a result of more rapid yield increase from 1990's and especially after 2000. At the same time the mean grain moisture at harvest decreased 13.6%. This proves introduction of hybrids, which dry down rapidly at the maturity stage. In analysed period the progress in this matter was lower (-0.24%) compared with this shown

by Bilski and Siódmiak (1994) for domestic hybrids in 1962 – 1992 (-0.28%). Also significant progress was achieved in plant lodging.

It is worth to mention the achieved resistance to diseases and pests. The most important pest in maize grown in Poland is European corn borer (ECB) (*Pyrausta nubilalis*). The damages caused by this pest, depending on weather, amount from few to 30% (Lisowicz 2001). As shown in Table 4. that damages caused by ECB decreased by 13.3% and this progress was achieved by traditional breeding. Fusarium diseases can be one of the most important maize diseases and the damage cause on average a 10% loss in yield but can increase up to 35% (Tekiela, Lisowicz 2001). Frit fly (*Oscinela frit*) and common smut (*Ustilago zea*) can affect maize in all maize growing regions in Poland. Intensive damage by frit fly is observed during cold springs, while common smut attacks under specific weather conditions. There are no hybrids significantly resistant to those pathogens in testing trials and on the registration list. The only exception might be the genetically modified hybrids with Bt gene, grown already in other countries, but not yet permitted to grow in Poland. Traditional breeding has also some success in this matter. There are some hybrids with certain resistance to ECB, *Fusarium* diseases, with the stay green character and high early vigour, which cause lower ECB infestation. Also some new hybrids are more resistant to smut. Although the progress can be observed in some hybrids, but on average it is rather a slow process.

PROGRESS IN SILAGE HYBRIDS

Till 2001 silage was the major usage of maize crop in Poland. Maize plants are excellent material for silage, widely used for intensive milk and beef production. Now it is more often pointed, that the best hybrids for silage are grain hybrids, but still in COBORU trials silage usage is treated separately for maize hybrids.

Early hybrids for silage have been introduced in COBORU trials as late as in 1994 (Table 5). This group was distinguished because of special need for early hybrids in the regions III and IV, where the vegetation period is relatively short. The value of silage hybrids is determined by higher share of grain in total dry matter. All maturity groups were represented by high number of hybrids. The lowest number (six) of tested hybrids was recorded in the medium early group in 1981 and 1984. but high competition caused more rapid progress. Although total number of tested silage hybrids in the last 20 years was significantly lower as compared with grain hybrids, but enough to create positive competition.

Total yield of dry matter is a basic parameter of feeding value of silage hybrids (Fig. 2). The medium late hybrids yielded higher than medium early ones, and the increase of yielding was also higher (38.8% and 33.4% respectively). Early hybrids tested within 7 years period showed

Table 5

Total number of maize hybrids in official testing for silage

Year	Polish hybrids			Foreign hybrids			Total hybrids		
	Early	Medium early	Medium late	Early	Medium early	Medium late	Early	Medium early	Medium late
1981	-	1	8	-	5	10	-	6	18
1982	-	5	7	-	4	17	-	9	24
1983	-	5	7	-	2	19	-	7	26
1984	-	4	5	-	2	13	-	6	18
1985	-	5	5	-	3	13	-	8	18
1986	-	6	7	-	5	9	-	11	16
1987	-	5	8	-	5	11	-	10	19
1988	-	6	6	-	9	12	-	15	18
1989	-	9	7	-	8	12	-	17	19
1990	-	9	4	-	13	12	-	22	16
1991	-	11	2	-	9	10	-	20	12
1992	-	7	2	-	17	9	-	24	11
1993	-	10	4	-	22	14	-	32	18
1994	4	6	3	10	19	13	14	25	16
1995	4	12	5	5	15	14	9	27	19
1996	2	7	5	5	17	11	7	24	16
1997	0	5	4	12	15	5	12	20	9
1998	1	3	5	7	9	6	8	12	11
1999	3	1	3	6	8	8	9	9	11
2000	3	6	2	10	10	8	13	16	10

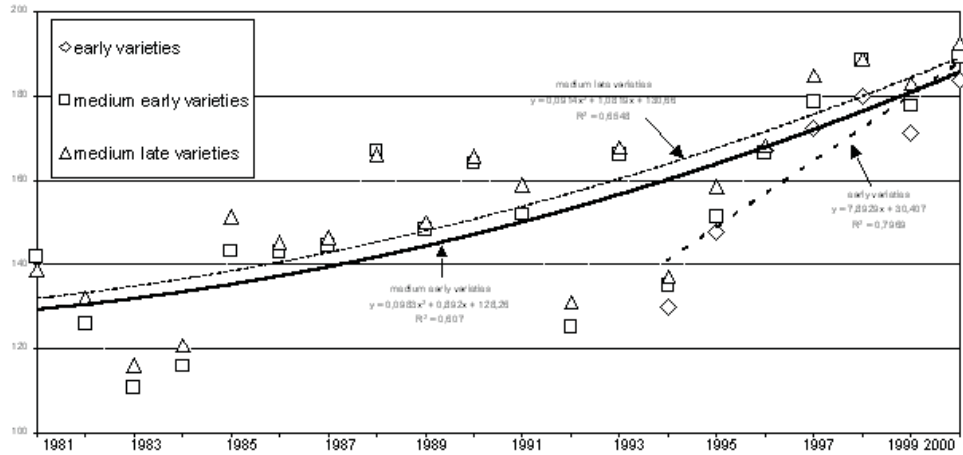


Fig. 2 Total dry matter yield [dt/ha]

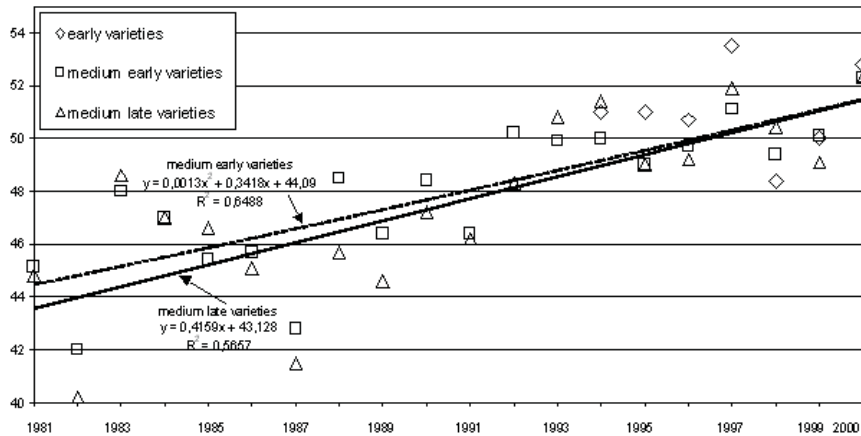


Fig. 3 Content of ears in total dry matter yield [%]

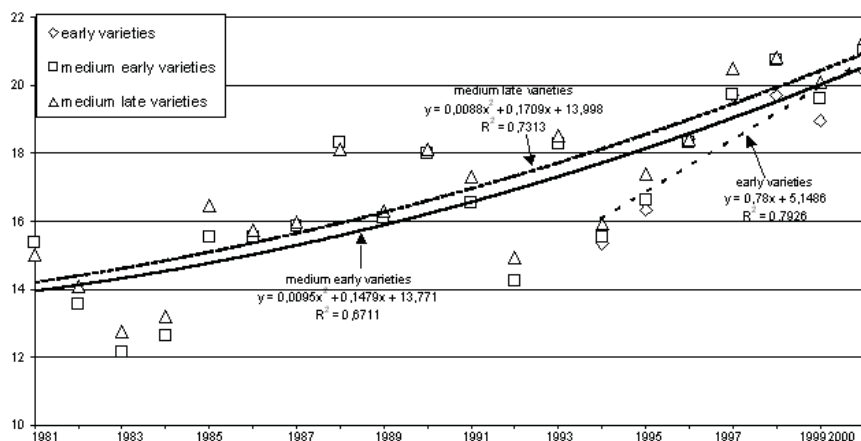


Fig. 4 Fodder units yield [thousands/ha]

the highest increase of total dry matter yield with a higher content of ears in total dry matter, which determines their feeding value (Fig. 3). The medium late hybrids showed a linear increase, although the progress in the medium early hybrids was lower (respectively 16.8% and 15.9%) and the curve is parabolic. The share of ears in the total yield of early hybrids was high and except for 1994 and 1998 was higher as compared with the hybrids of other maturity groups. This confirms that silage made from early hybrids is the most valuable. However it was not possible to find leading hybrids because of short testing period and a strong influence of weather conditions in 1994 and 1998.

The yield of fodder units increased relatively fast in all maturity groups. The highest, linear increase was observed in hybrids of the early

group (Fig. 4). For the medium early and medium late groups it amounted 36.8% and 42.4% respectively.

Summary of progress in silage maize hybrids tested in 1981 – 2000

The progress in silage maize hybrids should be considered as high. Within 20 years the annual total dry matter yield increased by 37.8%, i.e. 2.58 dt/ha annually. Bilski and Siódmiak (1994) shown lower increase (1.78 dt/ha) for period 1962 - 1992. They underlined significant increase in case of foreign hybrids, for which annual increase was 15 dt/ha in 1991 - 1992. In analysis of this study, yield of dry matter ears increased by 51.9%, very similarly as in analysis for 1962 - 1992 done by Bilski and Siódmiak (1994).

Fodder units increased by 37.5% (Table 6). The increase of fodder value of silage maize was also observed, expressed by 12.1% higher ear content in total dry matter yield. Podkówka and Podkówka (1994) write in summary of 38 years (1955 – 1993) about significant increase of silage quality.

Progress in silage maize breeding expressed by increase of total dry matter yield and selected characters

Table 6

Character	Mean annual increase	Increase in years 1981-2000
Total dry matter yield	2.58 dt/ha	37.8 %
Ears dry matter yield	2.48 dt/ha	51.9 %
Content of ears in total DM yield	0.33 %	12.1 %
Fodder units yield	440 o.u./ha	37.5 %

Number of hybrids in register of cultivars

Table 7

Year	Early and medium early hybrids				Medium late hybrids			
	Total	Polish	New	New Polish	Total	Polish	New	New Polish
1981	9	0	0	0	10	2	0	0
1982	8	0	1	0	9	2	1	1
1983	9	0	2	0	8	3	0	0
1984	8	1	1	0	8	3	0	0
1985	11	1	2	0	9	3	1	0
1986	11	1	0	0	10	3	1	0
1987	13	3	4	2	12	2	3	0
1988	13	4	1	1	13	1	2	0
1989	18	6	5	2	13	1	1	0
1990	12	5	4	0	7	1	5	1

Table 7

Continued

Year	Early and medium early hybrids				Medium late hybrids			
	Total	Polish	New	New Polish	Total	Polish	New	New Polish
1991	14	4	3	0	11	1	4	0
1992	19	7	6	4	15	1	4	0
1993	27	8	8	1	14	0	2	0
1994	31	9	6	1	17	1	3	1
1995	43	16	14	5	23	3	6	2
1996	45	8	6	0	27	4	4	1
1997	51	15	32	12	26	4	2	0
1998	59	17	11	2	27	4	5	0
1999	72	23	13	6	31	5	4	1
2000	79	27	11	2	35	6	5	0
2001	75	20	11	2	32	5	3	1

Table 8

Number of hybrids and their share in register of cultivars by cross type

Year	Single cross hybrids (SC)		Three-way cross hybrids (TC)		Double cross hybrids (DC)		Modified single cross hybrids (MSC)		Modified three-way cross hybrids (MTC)	
	Number	Share	Number	Share	Number	Share	Number	Share	Number	Share
1981	0	0	17	73.9	6	26.1	0	0	0	0
1982	0	0	12	66.7	6	33.3	0	0	0	0
1983	0	0	12	63.2	7	36.8	0	0	0	0
1984	0	0	11	64.7	6	35.3	0	0	0	0
1985	0	0	14	70.0	6	30.0	0	0	0	0
1986	1	4.5	14	63.6	7	31.8	0	0	0	0
1987	3	11.5	16	61.6	7	26.9	0	0	0	0
1988	3	11.1	15	55.6	9	33.3	0	0	0	0
1989	3	9.4	16	50.0	13	40.6	0	0	0	0
1990	5	26.3	4	21.1	10	52.6	0	0	0	0
1991	6	24	10	40.0	9	36.0	0	0	0	0
1992	8	23.5	16	47.1	10	29.4	0	0	0	0
1993	11	26.8	22	53.7	8	19.5	0	0	0	0
1994	16	33.3	26	54.2	6	12.5	0	0	0	0
1995	35	53.0	24	36.4	7	10.6	0	0	0	0
1996	15	25.0	38	63.3	7	11.7	0	0	0	0
1997	32	41.6	40	51.9	5	6.5	0	0	0	0
1998	40	46.5	40	46.5	5	5.8	1	1.2	0	0
1999	48	46.6	49	47.6	5	4.9	1	1.0	0	0
2000	54	47.4	54	47.4	5	4.4	1	0.9	0	0
2001	57	53.3	44	41.1	4	3.8	1	0.9	1	0.9

The number of registered hybrids is also worth to note. Presently there are 3 domestic and 14 foreign maize seed companies on Polish market. In the early and medium early maturity group, the number of registered hybrids increased rapidly up to 78 hybrids in 2000 and 75 ones in 2001 (Table 7). This includes also new hybrids. Number of hybrids applied for registration and already registered measure the activity of seed companies on Polish market. Domestic seed companies dominate on maize market and supply significantly cheaper seeds than the imported seeds. Both domestic and foreign companies were more interested in the early and medium early hybrids. In the medium late group, the number of registered hybrids was also increased in 1990's, but half of those in former groups and each year a lower number of hybrids is being registered in this group. Domestic companies applied in the last two years two hybrids in early and medium early groups and only one in the medium late group.

Within last 20 years, fundamental changes took place in the share of particular hybrid types (Table 8) in variety register. At the beginning most of hybrids was cheap from the seed production point of view, with low hybrid effect, i.e. tree-way crosses TC (app. 70%) and double-way crosses DC (app. 30%). Lately, the share of TC hybrids decreased to app. 40% and DC to only 4%. Single crosses SC with the highest hybrid effect were not registered in Poland before 1986. while last years their share in the register amounted approximately 50%. Michalski (2002) writes, that single hybrids were 67% of all registered in 2002. In 1998 Polish seed companies introduced a modified single cross (MSC) and in 2001 a modified three-way cross (MTC), which appeared for the first time in Poland. In seed production of these hybrid types, sister lines are used to decrease the costs.

Domestic seed companies have introduced lately very good hybrids like Glejt, Baca or Grom (from HR Smolice), comparable to foreign hybrids. Wide offer of domestic and foreign maize hybrids with better resistance to pests and diseases, a progress in crop management in maize grown for grain or silage, offer a good starting point for better farmer production. Hybrid guarantees the most effective way of maize production and the role of crop management is to introduce proper recommendations in such way to take advantage of hybrid potential.

CONCLUSIONS

Number of hybrids tested in registration trials, especially in 1990's, was large enough in all maturity groups to result in progress both in yielding and utilisation.

The yield increase in 1981 – 2000 up to 1.65 dt/ha annually, in all maturity groups, indicates rapid progress in yielding potential of new hybrids.

Low increase of yield in practical farming evidently shows a necessity of better crop management to take advantage of the full value of new hybrids.

Silage hybrids in registration trials showed an increase of the mean annual dry matter yield of 2.58 dt/ha, ear dry matter yield of 2.48 dt/ha, fodder units yield of 440 units/ha and an increase of ear content in the total dry matter by 0.33% annually. In the medium early and medium late groups, the curve illustrating the increase was parabolic, while for early hybrids it was linear, but in this case the analysed period was too short for full evaluation.

Rapid progress in dry matter yield and high ear content in total dry matter yield of early silage hybrids, which was faster compared with the medium early and medium late groups, indicates better ability of these hybrids to produce high value silage.

The share of Polish seed companies was significant. The number of grain hybrids increased mainly in the early and medium early groups. During the last 20 years foreign hybrids prevailed both for grain and silage.

Totally in 2000 there were 34% of Polish registered hybrids and 26.6% in 2001. out of which app. 20% were new. In the medium late group, the share of Polish hybrids was lower and amounted 17% and 16% in 2000 and 2001 respectively. In this group a new hybrid appeared in 2000 and no one in 2001.

At the beginning of the 20 years period there were 70% of three way hybrids (TC) and 30% of double way hybrids (DC). In the last years TC share dropped to 40% and DC to 4%. The most valuable single cross hybrids (SC) were not registered in Poland till 1986. but lately they constitute app. 50% of all hybrids.

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